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Experimental study for the single-stage and double-stage two-bladed Savonius micro-sized turbine for rain water harvesting (RWH) system

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Abstract

This paper examines the performance of the single-stage and double-stage two-bladed micro-sized turbine for the Rain Water Harvesting (RWH) System. RWH system is a method of collecting rain water and storing this free rain water into a tank before reused it for a particular purpose. In this paper, the performance study was focused on the electrical generation capability when Savonius turbine is used. The Savonius turbines were designed and built using an aluminium sheet with an aspect ratio (AR) of 1.8, with height (H) of 8 cm and diameter (D) of 4.5 cm. In this study, performance is compared between the single-stage and the double-stage designs in terms of electrical power generation when the incoming water flows from the water tank passing the micro-Savonius blades in the pipeline. From the finding, it was found that the designed and the built systems have good performance in terms of producing a constant voltage and current. The single-stage produced better performance than double-stage rotor, where power can be generated almost double. Rotor can rotate up to 1280 rpm when single-stage two-bladed Savonius rotor is used, compared to the double-stage rotor. The single-stage two-bladed Savonius micro-sized turbine also capable to light the 0.3 watt LED lamps.

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Keywords: savonius turbine; rain water harvesting; blade rotor; micro-sized; single-stage; double-stage

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1. Introduction

Rain water harvesting (RWH) system is a method of collecting rain water and storing this free rain water into a tank before reused it for a particular purpose [1]. This system has been widely used in most regions in the world which suited to their local climatic condition [2]. RWH system is typically used for domestic usage, agriculture and environmental management [1].

In general, RWH system can be managed using various methods. In modern application, the simple RWH system is typically consisting of a catchment area, storage tank, piping, treatment facility and supply facility. In developed countries, for instance in the UK and US, this simple RWH system is widely used to produce clean/filtered water that directly supplied to the customers for instance drink through the pipeline [3]. In certain areas, the RWH system is used for the general purposes in which not require treatment system such as for toilet flushing, watering plants, outside terrace cleaning and etc [4].

There are various papers discuss the model for developing RWH system for domestic uses [4][5], RWH for farm design [6], economic feasibility [7], model-based evaluations [8] and RWH implications [9-11]. But, no study was conducted in regards to the feasibility of micro electrical energy generation using the RWH system.

For locations with low wind velocities or low water flow velocities, it has been claimed that vertical-axis wind turbine (VAWT) is the most appropriate turbine for the purpose of small electrical energy generation. Savonius turbine is one of the VAWT types and was invented by Sigurd Savonious who is the Finnish engineer in the year 1994. This turbine consists two semicircular blades, which are fixed between two endplates. This blade will make the flow inside the rotor regular and its operation is based on the drag concepts. Savonius turbine is known may work more efficient in low water flow velocities because it has a large surface area to catch most of the water flow on the concavity of the blades. Larger torque can be created if larger surface area of the Savonius rotor is considered. The torque is produced by the force when water strikes the blades. Higher torque can be created when curving inward blades are used. Such turbine also can receive the whole water strike on the blade in any direction. Therefore, such turbine can rotate easier and automatically once the water strikes the blade [12]. Besides, the cost for this rotor design also cheaper than another type of VAWT rotors and the installation or maintenance work for this turbine is easier and easy to fabricate with cheaper cost [13][14]. In fact, it can produce a satisfactory performance, particularly to fulfill individual or small demands [15].

Therefore, this work addresses the experimental study of electrical energy generation feasibility using RWH system. In this work, study focuses on the designing, development and performance assessment on the blade rotation speed, generated currents, voltages and output power of the proposed system. Since Savonius turbine is being claimed can work well for low wind/fluid velocities application, such turbine is used in this study.

2. Experimental setup and procedure

2.1. The design and experimental procedure

The design process is executed by following a designed method flow. Process had been started by determining the appropriate design of the pipeline sizing. First, the crossover area section of the pipe is determined by surveying the available sizes of the pipe dimension in the market. Then, process is followed by determining the appropriate design of the micro-sized turbine rotor before determining the appropriate design of pipeline length and water tank size. To obtain the appropriate designs and fabrications of mentioned components of the proposed RWH system, 2 type of experiment has been set. For the first experimental, the water in the tank is released when the amount of water in 30 litres. Then, experiment is followed by doubling the amount of water to 60 litres. In each experiment, different length of pipeline (between the bottom level of the water tank and the height of the mounted turbine rotor) were used. The generated current, voltage, blade speed rotation and the time taken for the water flow from bottom water tank to rotor are measured. From these experiments, the optimum design of the RWH is determined.

2.2. Schematic diagram of RWH system model

The proposed RWH system model as depicted in Fig. 1 has the following components:

- Filter: To filter the rainwater from the rooftop from the rubbishes, leaves, debris, and etc. For the proposed system, a double-layer filter is used to ensure that the water from the roof is proper filtered before releasing the water flow through the pipe. The first layer is used to filter the big contaminants such as rubbish, leaves and others whilst the second layer is used to filter the micro and small contaminants such as sands, stones and others.
- Water storage tank: The water storage tank is used to collect the filtered rainwater that was flow from the rooftop. The storage tank which has a capacity to store water up to 60 litres was selected and used for the proposed RWH system. The storage tank was placed 2.75 metres from the ground, as illustrated in Fig. 1.
- Piping: Designed and fabricated to fix the suitable size of the proposed micro Savonius turbine that could provide optimum water flow rate, pressure and velocity. Water will be released from the collected water tank when water reached a certain measurement level (30 and 60 litres, depends on the set carried out experiment). The rectangular shape was chosen for the pipe compare to the circular one in order to provide smoother blades rotation and appropriate space for the blade rotor. The chosen geometry size for the pipeline is 4 inches times 2 inches, with height of 1.0, 1.5, 2.0 and 2.5 metres. This geometry sizes were chosen to find the best optimum water flow velocity in order to power 0.3 watt LED light bulb. The generated power by the blade rotor can be calculated using equation (1). Then, the estimation of the optimum water flow velocity can be estimated by rearranging equation (1) into equation (2).

$$P = \frac{1}{2}\rho A C_p U_{opt}^3 \tag{1}$$

$$U = \left(\frac{2P}{\rho A C_p}\right)^{\frac{1}{3}} \tag{2}$$

where P = power output, C_p = power coefficient, p = density of water = 999.97 kg/m³, A = area of rotor and U = velocity of water. Assumed that C_p = 0.4.

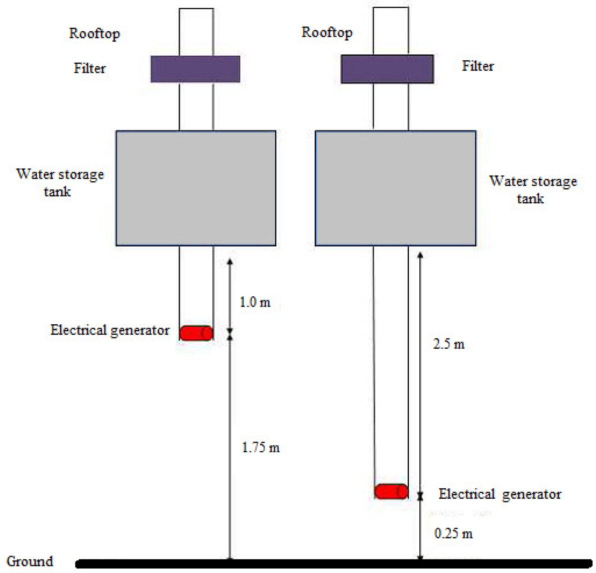

Fig. 1. Block diagram of the proposed electrical generation system using RWH system.

By considering the available pipeline in the market (4 inches by 2 inches) and by manipulating the parameters of pipe's height and the pipe's surface area, the instantaneous water volume and the water flow rate can be estimated using equation (3) and (4), respectively. Hence, the instantaneous water velocity can be estimated by rearranging equation (4) into equation (5). Power then can be estimated by suing equation (6).

$$Vol = A \times h \tag{3}$$

$$Q = \frac{Vol}{t} = \frac{A \times h}{t} = A\bar{v} \tag{4}$$

$$\bar{v} = \frac{Q}{A} \tag{5}$$

$$Pg = V \times I \tag{6}$$

where Vol = water volume, h = water height, t = time (assumed as 2 seconds) and $\bar{v}$ = velocity of water with the specified water height, Pg = generated power , V = measure voltage and I = measure current.

Generator: To generate electrical energy when connected to the micro-sized Savonius turbine via shifting components. A 6 Volts DC motor (from a used toy racing car) has been used as a generator to convert the mechanical to electrical energy, as depicted in Fig. 2.

Blade rotor: The micro-sized two-bladed Savonius VAWT rotor is mounted into a shaft shifting system to enable the connected generator produces electrical signal when the shaft is rotating. The micro-sized Savonius blades were designed and built using an aluminium sheet with an aspect ratio (AR) of 1.8, with height (h) of 8 cm and diameter (d) of 4.5 cm, as shown in Fig. 3.

Fig. 2. The generator for the proposed RHW system.

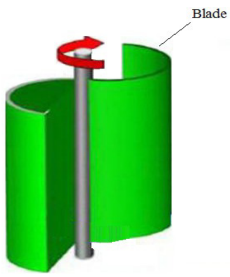

Fig. 3. Schematic drawing of the single-stage Savonius blade rotor.

Meanwhile, the single-stage and the double-stage of the proposed Savonius blade rotor are shown in Fig. 4 (a) and (b), respectively. The blades were made of semi-cylindrical half of the diameter and were assembled to have an overlap and separated by 180 degrees. However, for the double-stage rotor, two rotors were mounted in a single shaft, but have overlapped 90 degrees from the first rotor.

(a)

(b)

Fig. 4. The micro-sized Savonius rotor for the proposed RHW system; (a) single-stage two-bladed, (b) double-stage two-bladed.

3. Results and Discussions

3.1. Single-stage Savonius blade

a. Water volume fixed at 30 litres

Table 1 shows the collected data for the single-stage turbine when the water volume is fixed at 30 litres in the water tank before released into the pipeline. From Table 1, the blade rotations that were measured using a tachometer shows that the designed rotor capable to rotate fast to generate some amount of power. This is because the designed rotor has a good efficiency in rotating the blades. From the results, it was found that the generated power can be achieved up to 0.22 watt when the pipeline is designed and fabricated in 1.0 metre long. However, when longer pipe is used, the generated power decreases; this is due to the longer time taken for the released water from the tank to reach or hit the blades to spin, as proved by the measure time taken as listed in the third column of Table 1. Faster blade rotation affects the generated current and voltage as well, in which with faster blade rotation, these values can be improved better.

Table 1. The measurement results for the single-stage turbine when water volume is set at 30 litres.

Height from the bottom water tank to the mounted rotor (m)	Height from the mounted rotor to the ground (m)	Time taken for the water flow from bottom water tank to rotor (s)	Blade speed (RPM)	Current (mA)	Voltage (V)	Power (watt)
1.0	1.75	44	1225	107.6	2.02	0.22
1.5	1.25	47	1208	104.0	1.95	0.20
2.0	0.75	52	1194	100.3	1.92	0.19
2.5	0.25	57	1178	69.60	1.87	0.18

As summary from Table 1, it can be said that the generated power can be increased better when the height from the bottom water tank is placed shorter to the mounted blade rotor. Besides, it also can be summarized that faster blade rotation can contribute to increase generated current and voltage and then the generated power.

b. Water volume fixed at 60 litres

Table 2 shows the collected data for the single-stage turbine when the water level is fixed at 60 litres in the water tank. From Table 2, it can be seen that similar trend as obtained in Table 1 is shown in this experiment, in which power is increases when the pipeline is designed and fabricated shorter. The current, voltage and blade rotation also increased better. When higher water level is considered, the power can be increased almost double when 1 metre pipeline is used. But, when the pipeline is designed longer, power only slightly increased though the water level has been doubled. In fact, almost same power can be generated when 2.5 metres pipeline is used though the amount of collected water is increased doubled before release the water to the pipeline.

However, from the comparison between the measure data from Table 1 and Table 2, it can be seen that better power output can be generated (up to 0.3 watt) when the water level in the tank is increased double when 1.0 metre long pipeline is used. This is due the increment of the generated current, voltage and blade speed rotation. Current can be generated from 106.7 mA up to 114.5 mA in this experiment. Voltage also can be increased higher from 1.78 V to 2.61 V. With increment of water level, the volume of the water is increased.

Table 2. The measurement results for the single-stage turbine when water volume is set at 60 litres.

Height from the bottom water tank to the mounted rotor (m)	Height from the mounted rotor to the ground (m)	Time taken for the water flow from bottom water tank to rotor (s)	Blade speed (RPM)	Current (mA)	Voltage (V)	Power (W)
1.0	1.75	24	1280	114.5	2.61	0.30
1.5	1.25	28	1263	112.0	2.40	0.26
2.0	0.75	33	1250	109.4	2.10	0.23
2.5	0.25	37	1231	106.7	1.78	0.19

3.2. Double-stage Savonius blade

a. Water volume fixed at 30 litres

Table 3 shows the collected data for the double-stage turbine when the water volume is fixed at 30 litres in the water tank before released into the pipeline. From Table 3, similar trends that have been mentioned in section 3.1.b also demonstrated, where power is increases when the pipeline is designed and fabricated shorter. The generated current, voltage and power also proportional to the number of the blade speed rotation. Using double-stage for this experiment, power can be generated from 0.19 watt to 0.15 watt. Obvious power increment is obtained when shorter height between the bottom tank and the mounted rotor.

Table 3. The measurement results for the double-stage turbine when water volume is set at 30 litres.

Height from the bottom water tank to the mounted rotor (m)	Height from the mounted rotor to the ground (m)	Time taken for the water flow from bottom water tank to rotor (s)	Blade speed (RPM)	Current (mA)	Voltage (V)	Power (W)
1.0	1.75	24	920	80.8	1.83	0.15
1.5	1.25	28	888	77.1	1.75	0.13
2.0	0.75	33	855	73.2	1.70	0.12
2.5	0.25	37	821.7	69.6	1.60	0.11

b. Water volume fixed at 60 litres

Table 4 shows the collected data for the double-stage turbine when the water volume is fixed at 60 litres in the water tank. Compared to the results that were listed in Table 3, this experiment provides only slight increment of power output. From the comparison between the measured data in Table 1, Table 2, Table 3 and Table 4, it can be seen that better power output can be generated (up to 0.3 watt) when the single-stage is used, and when water volume in the tank is increased double (60 litres) when 1.0 metre long pipeline is used. However, among these four tables, it can be observed that power is only increased very slightly when water volume is set double, when double-stage rotor is used. However, Table 3 shows the lowest performance among all the executed experiments. This is due the slowest blade speed rotation of the blades, thus weakening the generated current, voltage and output power. With increment of water level, the volume of the water is increased. Thus, increasing the water pressure in the pipeline, consequently, causing the designed Savonius rotor blade work more efficient from the first experiment (Table 1). The overall performance between these four experiments can be depicted from Fig. 5.

Table 4. The measurement results for the double-stage turbine when water volume is set at 60 litres.

Height from the bottom water tank to the mounted rotor (m)	Height from the mounted rotor to the ground (m)	Time taken for the water flow from bottom water tank to rotor (s)	Blade speed (RPM)	Current (mA)	Voltage (V)	Power (W)
1.0	1.75	44	1100	89.7	1.91	0.17
1.5	1.25	47	1057	87.4	1.89	0.16
2.0	0.75	52	1014	85.1	1.76	0.15
2.5	0.25	57	970	82.8	1.70	0.13

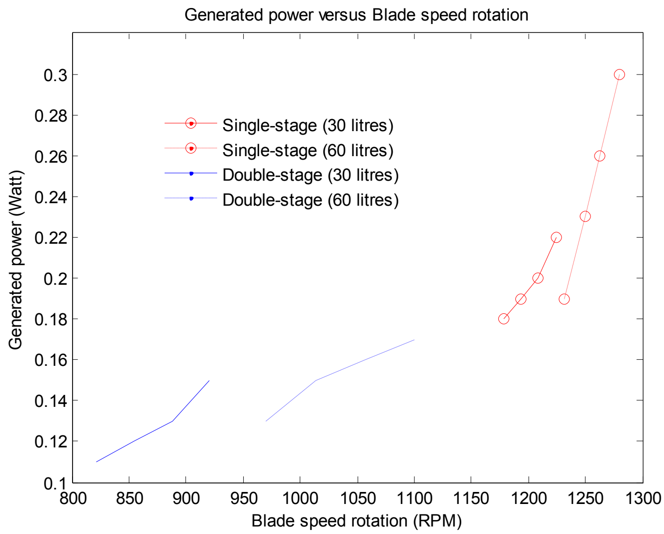

Fig. 5. The generated power versus blade speed rotor, for different water volumes in the storage tank.

From Fig. 5, it shows that single-stage with 60 litres water volumes gives superior performance than the others, where power can be generated up to 0.3 watt with blade speed rotation around 1280 RPM, whereby double-stage with 30 litres water volume gives poorer performance where the blades spin slowest compared to others. Hence, with single-stage and 60 litres water volume, 0.3 watt LED can be lighted successfully. Therefore, it is projected that if water volume is increased, more power can be generated, thus more LEDs can be lighted.

4. Conclusion

From the executed study, the proposed RWH system using a micro-sized two-bladed Savonius rotor, considering single-stage rotor and double-stage rotor has been successfully designed and built, for the purpose of electrical generation. The basic principle works of each system components, including the theories and equations, the method and the research process, and also the findings have been discussed and explained in detail in the preceding sections. In the executed study, testing was repeated for several times before recorded and tabulated the results into the appropriate manner. From the obtained results, it can be concluded that the electrical generation using the proposed RWH system depends highly on the efficiency of the ability of blade rotor's rotation. When the speed of rotor rotation is increased, the output power can be increased as well, as has been proven from the executed experimental. The height between the bottom storage tank from the mounted rotor also influence the rotor performance. When the height is shorter, water will strike the rotor shortly and thus, the rotor can automatically spin faster compared to the condition when longer height is set. The single-stage two-bladed Savonius rotor can rotate up to 1280 rpm when 60 litres water in the tank is stored before released the water to flow into the pipeline. In terms of performance, single-stage rotor produced better performance than double-stage rotor. Power can be generated almost double than the double-stage rotor when single-stage rotor is used, thus supplying a 0.3 watt LED lamp successfully. Based on the findings that have been observed and obtained from the executed study, it can also be concluded that the proposed RWH system is project may give a good potential to be used and commercialized for home application if the designed system is further upgraded to increase the entire system performance and reliability. Also, it can be conclude that the Savonius rotor is applicable to be used as the RWH's turbine since this rotor manage to rotate fast, simple and easy to be designed and employed.

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